

# Research at NASA on Human Response to Sonic Booms.

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## ABSTRACT

NASA used its sonic boom simulator to study human response to shaped sonic booms and concluded that a loudness metric, such as Perceived Level, predicts human reaction to outdoor booms more accurately than overpressure. To investigate the importance of indoor phenomena (rattle, reverberation) under controlled laboratory conditions, NASA is building an "indoor sonic boom simulator." The intention is to develop a psychoacoustic model that describes human response as a function of boom shape (spectrum), boom intensity, reverberation, and varying rattle characteristics.

## 1. Introduction

NASA's High Speed Research (HSR) program in the 1990s was intended to develop a technology base for a future 300-passenger High-Speed Civil Transport (HSCT). As part of this program, the NASA Langley Research Center sonic boom simulator (SBS) was built and used for a series of studies of the subjective response to sonic booms. At the end of the HSR program, an HSCT was deemed impractical, but since then interest in supersonic flight has reawakened, this time focusing on a smaller aircraft. The demonstrated ability to design a "low-boom" aircraft has encouraged re-appraisal of the FAA ruling that supersonic flight should be banned overland.

This paper presents an overview of work on human response to sonic boom completed at NASA during the 1990s. Also discussed is a 2005 study comparing sonic boom simulators and NASA's most recent project, the construction of a facility to enable the simulation of booms as heard inside a building, is introduced.

## 2. Response To Sonic Boom 1990-1996

During the 1990s, NASA Langley Research Center conducted three groups of studies on sonic booms: laboratory, "in-home" and field. These three complementary parts consisted of

(a) laboratory studies, which have very good control over the sound stimuli that the subjects hear but require a very abnormal listening environment;

(b) an "in-home" study, where sounds are played through loudspeakers in people's homes, thus improving the realism of the environment but reducing the control over the sound field;

(c) field studies, with a completely normal environment but no control of the sonic booms and relatively poor knowledge of the precise details of the sound exposure. The "acceptability" of or "annoyance" caused by a sound is affected by many factors. In a laboratory situation, while some of these factors are under control, others may be missing. Thus ratings of sounds can be considered as accurate relative to one another, but not in an absolute sense. The in-home study moves closer to absolute measurements and the field studies measure absolute, real reactions. A compilation of the laboratory and in-home studies, with details of the findings, is given in Leatherwood *et al.* [1].

## 2.1 Laboratory Studies

The laboratory experiments were designed to (a) develop an improved understanding of sonic boom subjective effects; (b) quantify in a systematic and comprehensive manner the loudness and annoyance benefits due to intentional sonic boom shaping as well as distortions due to passage through walls, ground reflections, and atmospheric propagation; and (c) assess various noise descriptors as predictors of sonic boom subjective effects. To study these factors, NASA Langley built a Sonic Boom Simulator (SBS), a person-rated, airtight, loudspeaker driven booth, carpeted and lined with foam to reduce acoustic resonances, and free of loose objects capable of creating rattles. Input waveforms are computer generated and preprocessed to compensate for non-uniformities in the magnitude and phase characteristics of the frequency response of the booth and sound reproduction system. Preprocessing is accomplished by the use of a digital broadband equalization filter. One significant finding from the series of 14 studies conducted in the SBS were that subjective reactions to simulated sonic booms were predicted well by calculated loudness metrics, such as Steven's Perceived Level (PL). Such metrics as unweighted or C-weighted dB or peak overpressure were poor predictors of human response.

## 2.2 In-home Study

The assessment of sonic boom exposure needs to include both the characteristics of individual booms and the number of them that occur. This is difficult to study in a laboratory situation. To enable the investigation of more realistic multiple-event environments, Langley Research Center completed an "in-home" study in which simulated sonic booms were played through loudspeaker systems in people's homes. Various scenarios involving different numbers of booms at different levels were played, with participants giving annoyance judgments after a day's exposure. The study confirmed that the increase in annoyance resulting from multiple occurrences can be modeled by the addition of the term  $10 \times (\log(\text{Number of Occurrences}))$  to the sonic boom level.

## 2.3 Field Studies

The third part of NASA Langley Research Center's program during HSR to study subjective response to

sonic boom was a series of field studies in which the responses of community residents experiencing supersonic overflights were measured, together with their boom exposures. This study was unique in that no other study has investigated the reactions of people routinely exposed to sonic booms over a long time period. As reported in Fields [2], the study found that sonic boom annoyance increased as the number and/or level of the booms increased. Large differences noted in responses from two localities were not attributable to sonic boom exposure, but were explained in part by differences in attitudes towards the “noise makers” and differences in exposure to low altitude, subsonic aircraft flyovers.

### 3. Simulator Assessment

As aircraft that can produce low-intensity booms in normal flight do not yet exist, it is necessary to use simulators to study the effects of these booms on people. However, when people experienced in listening to booms heard the simulations in the SBS, they often remarked that “something was lacking” and the simulations were not realistic. In 2005 a series of studies was performed to evaluate the realism of booms presented using three sonic boom simulators, in conjunction with the FAA/NASA/Transport-Canada PARTNER Center of Excellence (Sullivan [3]). The three simulators were the SBS, Lockheed Martin’s boom simulator and the Gulfstream portable boom simulator. The Lockheed Martin simulator is a very similar design to the SBS, both being airtight booths that achieve the characteristic sonic boom N-wave shape by compressing the air within the booth. The Gulfstream simulator is a folded-horn design which creates a pressure wave that travels past the listener into an anechoic termination. This arrangement excludes the very lowest frequencies (below ~7Hz) from the simulation.

One study showed that listeners recently exposed to booms from real aircraft rated the reproductions in the Gulfstream simulator as generally between “moderately realistic” and “very realistic.” Therefore the Gulfstream simulator made a suitable “reference” for the three-way inter-simulator comparison.

The results from three other tests, comparing the NASA and the Gulfstream simulators, and the Lockheed Martin and the Gulfstream simulators, showed that “post-boom noise” (the “rumble” occurring after the boom) is essential for realistic simulation of sonic booms. The duration of the post-boom noise should be at least about 1.5 s. Longer duration does not improve realism ratings greatly, but shorter duration causes a rapid decrease in perceived realism. Other factors studied, low frequency energy below 7 Hz and ground reflection, were not found to significantly affect realism ratings.

Of the three simulators studied, the Gulfstream SASSII simulator was rated as somewhat more realistic than either the NASA or the Lockheed booth. The superior performance of the Gulfstream simulator could

be due to its fundamentally different design or to subtle differences in the equalization filters.

### 4. Response To Sonic Booms Heard Indoors

Earlier field studies (summarized in Sutherland *et al* [4]), though confined to conventional booms, typically with overpressures greater than 1 psf, showed the importance of indoor phenomena (such as rattle and reverberation) as well as non-acoustic phenomena (for example, startle). To further investigate this phenomenon, under controlled laboratory conditions, NASA is building an “indoor sonic boom simulator” (Klos *et al* [5]). This is a room built using standard US construction methods and materials, two walls of which will be driven by arrays of loudspeakers. One of these walls will contain a window, which will be tightly fitted so that it produces no rattle sounds. However, small loudspeakers, hidden within the room, will be used to simulate rattles from the window and other objects within the room. The sound so produced will be repeatable (unlike the sounds from real rattling objects) and can be varied parametrically. Test subjects positioned inside this room will be asked to rate the sounds they experience (including the controlled rattle) using a variety of psychometric methodologies. The boom characteristics and the rattle sounds will be independently controllable. The objective is the development of a psychoacoustic model that describes the human response as a function of boom shape (spectrum), boom intensity, reverberation, and varying rattle characteristics. The room construction is scheduled for completion in February 2009.

### 5. References

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